

ELECTRONIC FUNDAMENTALS

SERVICE PRACTICES 40

PRACTICAL TELEVISION ANTENNAS AND TRANSMISSION LINES

**40-1 Practical Television Antennas
Compared with Radio Antennas**

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Service Practices 40

INTRODUCTION

This lesson discusses practical television antennas and special antenna transmission lines. Since you have already learned the basic principles of standard AM broadcast antennas, you are already prepared to understand practical television antennas; the same basic principles apply to television antennas. But, due to certain practical considerations, practical television receiver antennas are different from standard AM broadcast antennas. These practical considerations are:

1. Television is broadcast at higher frequencies than standard AM radio. Therefore, television wavelengths are shorter than radio wavelengths.
2. Television signals are horizontally polarized but radio signals are vertically polarized.
3. The band of frequencies that a television receiver antenna is required to handle is much wider than the band of frequencies that a radio receiver must handle.

40-1. PRACTICAL TELEVISION ANTENNAS COMPARED WITH RADIO ANTENNAS

Now that the reasons for the differences between practical television antennas and radio antennas have been stated, let us examine exactly what these differences are.

Differences Due to Shorter Wavelength. Because television wavelengths are so short, it is possible to make a practical television antenna a half-wavelength long. As you have already learned, half-wavelength antennas are resonant. Therefore, it is possible to have resonant television antennas.

Practical television receiving antennas are usually of a length equal to one-half the wavelength of one of the lower frequencies assigned to television. Contrast this with AM radio receiving antennas, which are usually much less than a half-wavelength at the frequencies assigned for the standard AM broadcast band. As a result, standard AM receiver antennas (except for loop antennas) are too short to be resonant.

Since television antennas are resonant, they are directional. Just as you can use a radio loop antenna to pick up maximum signal from one direction and discriminate against interference signals coming from other directions, you can use the television antenna directionally. This directional property is of great advantage in television. Since television signals have such short wavelengths, they are easily reflected from buildings and other large structures. By means of making use of the directional properties of the television antenna, the antenna can be placed so that it has maximum pickup of the wanted broadcast signal and minimum pickup of the reflected signals. If the antenna did not reject the reflected signal, *reflections* (double images), would appear on the screen.

Another effect of the short wavelength of frequencies assigned to television is on the *propagation characteristics*, or behavior of the radiated television signal while it is on its way to the receiver. The television signal decreases more in strength per unit of distance from the transmitter than the radio signal. The television signal decreases more in strength and is more distorted if it must pass through an obstacle, such as a building, to reach the receiver. Also, unlike radio signals, the television signal does not tend to follow the curvature of the earth. In general, the television signal is not usable at a place that is beyond the earth's hori-

zon to a viewer located where the transmitter antenna is located. Generally, television signals are usable only at receiver locations from which the transmitter antenna can be seen. This is called the *line-of-sight* distance from the transmitter. This rule applies mainly to distance. If the view of the transmitter antenna is obscured by an obstruction, such as a building, the signal may still be receivable especially if the distance to the transmitter antenna is short and therefore the signal is very strong. Nevertheless, obstructions do lessen reception.

Also, because television wavelengths are so short, the length of the transmission line or lead-in connecting the antenna to the receiver is usually equal to many wavelengths. The lead-in would be resonant and behave like a series of resonant circuits strung together between antenna and receiver rather than like a simple connecting lead if a special transmission line were not used. The transmission line used should not be resonant. The amount of signal voltage that a resonant line would deliver to the receiver would be equal to the signal voltage at the terminals of the antenna to which the transmission line were connected only if the resonant transmission line happened to be a whole number of wavelengths long. This condition can be met for only one channel frequency. It cannot be met for all channels using only one line. If you think of a resonant line as a string of resonant circuits connecting receiver to antenna with each wavelength distance along the line representing one resonant circuit, you will realize that, if the line is not equal in length to a whole number of wavelengths, the last *circuit* in the string will not be as long as the others. The last *circuit* is the one to which the receiver is connected. And connecting the receiver in this way is roughly equivalent to tapping down on a resonant coil. When you tap down on a coil, the coil acts as a voltage divider; you get less voltage at the tap than you would across the coil.

We have just explained the behavior of a resonant transmission line by comparing it with the coil-capacitor kind of resonant circuit with which you are more familiar. Usually, however, resonant transmission line sections are analyzed in terms of stand-

ing waves (see Theory Lesson 32) that result from reflection at the end of the line, of the signal travelling on the line. The signal is reflected back to the line instead of being delivered to the receiver connected to its terminals. (In this booklet, you will learn more about standing waves on transmission lines.)

Since, for connecting a television receiver to its antenna, a resonant transmission line is not wanted, something must be done to make the transmission line nonresonant. Potentially, all lead-in wires are resonant. But if a lead-in transmission line is terminated at the receiver in a certain critical value of resistance, the line will be nonresonant. In a sense, the normally resonant line will be damped in the way a parallel resonant circuit is damped when a load resistor is connected across it. The line will be most effectively damped when the resistor draws the most power from the line. This occurs when the terminating resistance is of a value in ohms equal to the value of the self-impedance of the line, because then the resistance matches the impedance of the line. And, as you know, the most power is transferred between circuits when impedance is matched. The self-impedance of an unterminated transmission line varies from point to point along the line. How it varies depends upon the behavior of the reflected waves on the line. The behavior of the reflected waves on the line depends, in turn, upon the frequency of the signal carried on the line. Suppose that you measured the current and voltage at a particular point on an unterminated resonant line and from these measurements you were able to calculate the self-impedance of the line at that point ($R=E/I$). Having calculated the impedance of the line, you might think that the line impedance could be matched if the line were terminated at the point of measurement with a resistor equal in value to the line impedance that you calculated. But this is not so; you would not be matching the impedance of the line. Terminating the line would alter the behavior of the reflected waves on the line and thus alter the self-impedance of the line at the point at which you terminated it. The self-impedance would no longer be what you calculated because a new voltage and current would exist at the

point where you made your measurements. However, if you tried many other values of resistance, you would find one critical value that, when it terminated the line, matched the changed self-impedance of the line. For every transmission line, there is one value of terminating resistance that — when it is placed across the end terminals of the line — causes the self-impedance at the terminals to change from what it is when the line is not terminated *to a value equal to the terminating resistance*. This is the critical value of terminating resistance needed to match the impedance of the line and draw most power from the line. This is the value to most effectively damp the line and make it nonresonant. Since, when this critical value of resistance terminates a line, the line assumes a self-impedance equal to the terminating resistance, this value of resistance is said to be the *characteristic impedance* of the line. Fortunately, once the value of the characteristic impedance of a line is found, it holds true for all frequencies within a very wide range of frequencies and at every point on the line. This means that a line of known characteristic impedance can be made nonresonant by proper termination. Even if the line is made longer or shorter, its characteristic impedance does not change (except for lengths that are very small compared to a wavelength). Even if the frequency of the signal that is carried on the line is increased or decreased, its characteristic impedance does not change.

Although characteristic impedance is the same for all line lengths of a particular type of transmission line and for all signal frequencies picked up by that line, it is not the same for all transmission lines. The characteristic impedance of a transmission line depends upon the inductance per unit of length of the wire conductor in the line and upon the capacity (per the same unit of length) to ground or, in a two-wire line, the capacity to the other conductor. This inductance depends upon the *diameter* of the wire conductor — not upon its length which is the same unit value for all lines measured. The capacity depends upon the spacing of the conductor from ground or the other conductor and upon the dielectric strength

of the material filling the space. (The space may be occupied by air or by a solid or plastic insulating separator.) For example, a two-wire transmission line made up of thick wires closely spaced will have a certain value of characteristic impedance that will hold true for all lengths of the line and for signals of all frequencies. Another two-wire transmission line made up of thin wires widely spaced will have a value of characteristic impedance that is different than the value of characteristic impedance of the first line; the value of characteristic impedance of this second line will also hold true for all line lengths and signal frequencies.

It is not practical to use a single wire radio-like lead-in to interconnect a television receiver and antenna because the characteristic impedance such a lead-in will have when it is in place cannot be predicted in a practical way. It might have any characteristic impedance, depending upon how far it is spaced from ground or grounded objects after it has been installed. In practice, specially made two-wire transmission lines are used for television. The spacing of the wires is held constant by some kind of insulating spacer, and the characteristic impedance is the same regardless of how the line is installed. The fixed spacing of the two wires makes it possible to predict the value of the characteristic impedance. In practice, the value of the characteristic impedance is specified by the manufacturers of the line. The most common standard values of characteristic impedance for manufactured lines is 300 ohms or 72 ohms. The standard input resistance at the antenna input terminals of the television receivers designed to terminate these lines is also 300 ohms and 72 ohms. So practical television receiver-antenna transmission lines are nonresonant lines and therefore deliver almost the same proportion of antenna signal voltage to the receiver for all channels. Also, the lines perform consistently in all installations. The lines are nonresonant because they are impedance-matched at the receiver terminals. They are nonresonant when they are terminated in an impedance-match because then most energy or power is transferred to the matched load and least energy or power is reflected back on the

line. In this sense, it is desirable to have maximum transfer of energy from antenna to receiver. However, remember that, basically, the strength of the picture depends upon how much signal voltage — not energy or power — is applied to the antenna terminals of the receiver. The picture amplifiers in the receiver to which the signal from the antenna is delivered are voltage amplifiers. They need consume almost no signal power in order to function. When the entire system is matched, the antenna delivers maximum energy or power to the transmission line and the line delivers maximum energy or power to the receiver. Under these conditions, most voltage is obtained when most energy or power is delivered, when the strongest signal is being picked up. However, if the entire system is not matched due to a defect or otherwise, maximum voltage may be obtained when maximum power is not delivered. Some television master antenna systems are designed on a partially unmatched basis. In this case, maximum signal voltage can be delivered to receivers in the system without also delivering maximum energy or power.

In contrast to television, most AM broadcast radio receiver antenna systems are not matched to deliver maximum energy or power. Instead they are designed to have high impedances that load the antenna as little as possible and so get most voltage from the antenna. An exception is the radio antenna systems called *low impedance systems*, which are not widely used.

Differences Due to Polarization. In contrast to standard radio signals which are polarized vertically, *signals transmitted by television broadcast stations are horizontally polarized*. This standard was decided upon in order to take advantage of the directional characteristics of the straight (not looped) half-wave antennas that are most suitable for reception of signals at the short-wave frequencies assigned to television.

If vertical polarization were used, the straight antennas would be directional in the vertical plane. To obtain a directional characteristic in the horizontal plane where,

in practice, it is needed, looped receiver antennas would have to be used because, according to basic antenna theory, only loop-type antennas are directional in the horizontal plane when vertical polarization is used. By using horizontal polarization, a directional characteristic in the horizontal plane can be obtained from straight antennas. (With horizontal polarization, loop antennas are not directional in the horizontal plane and, therefore, loops are not used to receive television signals.)

Differences Due to Bandwidth. One of the most severe requirements that a TV antenna must meet is that of exceptional bandwidth. It must perform satisfactorily over the very wide range of frequencies allocated for television broadcasts. The lower half of the VHF TV band is 34-mc wide (from 54 mc to 88 mc). The upper half is 42-mc wide (from 174 to 216 mc). The half-wave dipole, is able to respond reasonably well over these frequency bands if its length is such that it resonates at a frequency near that of channel 2, the lowest channel in the VHF bands. For the lower VHF band (54 to 88 mc), it functions as a half-wave antenna, slightly mismatched for signals near the 88-mc end of the band, but still effective. For the higher VHF band (174 to 216 mc), it functions as a $3/2$ -wave antenna near the 174-mc end of the band, and as a 2-wave antenna near the 216-mc end of the band. Thus, the ability of the half-wave dipole to resonate broadly at multiples of its fundamental frequency makes it have a very broad-band response adequate for the VHF TV bands. In one or other of its improved forms it is the basis of most commercial as well as of most home-made designs.

40-2. THE HALF-WAVE DIPOLE

Let's compare the behavior of a quarter-wavelength of transmission line with a half-wave dipole; both have the same electrical length of conductor, but in the transmission line (Fig. 40-1a), the two quarter-wave lengths of conductor are arranged close together, side by side. In the dipole (Fig. 49-1b) the two lengths are in line, and end to end. This difference in physical arrangement of the same

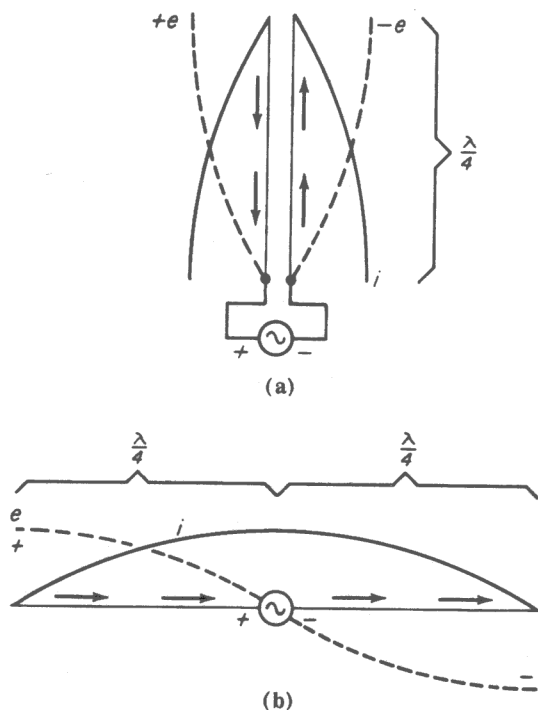


Fig. 40-1

length of conductor makes a profound difference in their action.

In Fig. 40-1, the straight lines represent the quarter-wave lengths of conductor. In each case, the r-f generator supplies voltage at the resonant frequency. At a given instant, the polarity of the generators may be as shown, and there are standing waves of voltage (dashed lines) and current (solid lines) as shown. Because the standing wave of voltage is maximum at the ends of a half-wave dipole, the potential difference at the ends puts the maximum intensity of electric field into the space around it. Similarly, the standing wave of current is maximum at the center of a half-wave dipole and causes an electromagnetic field at right angle to the electric field. The energy in both fields is equal. The dipole provides the conditions for efficient radiation and for efficient coupling of energy into space.

Now note the quarter-wave section of transmission line at Fig. 40-1a. It is like a dipole folded up so that its arms, instead of being outstretched end to end, are folded forward until they are side by side. Note particularly the direction of current flow in the two conductors. The conductors are very

close together and the flow of current is in opposite directions. The fields around each quarter-wave conductor are of opposing polarity and, since the conductors are close together, the fields almost completely cancel. Thus, the transmission line has very little ability to radiate, but it has unimpaired ability to carry r-f energy. This makes it an excellent link between antenna and receiver, or between antenna and transmitter. It can conduct the energy from one to the other without wasting appreciable energy by radiation due to an imperfect cancellation of field about the transmission line. While we are operating a transmitter, we want all the radiating to be done by the antenna. While we are operating a receiver, we do not want any of the energy collected from space by the antenna to be radiated into space again by the transmission line.

The simple dipole, as we have just reviewed it, is seldom seen on a rooftop, because a better antenna can be made by modifying it. It can be improved with respect to bandwidth, terminal impedance, directivity and gain.

Broad-Band Dipoles. The graph in Fig. 40-2 shows the response of a simple dipole over the entire VHF band. (The response is idealized — little kinks are taken out, so that only the general curve is shown.) Although such a response is remarkably broad, there is a falling-off at the upper end of the VHF band. It is desirable to improve this response. The simplest way to increase the bandwidth of the dipole is to make the two

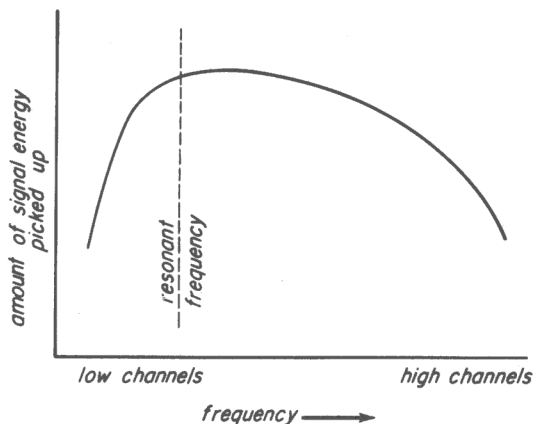


Fig. 40-2

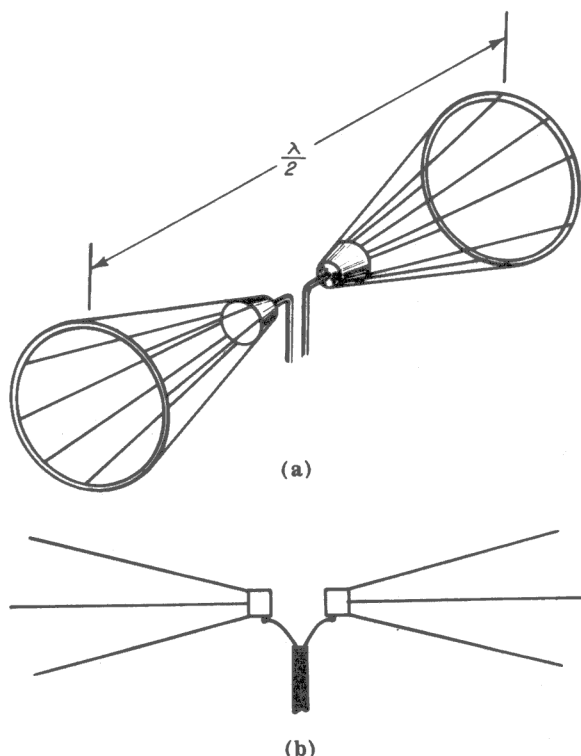


Fig. 40-3

quarter-wave segments of thicker conductors, such as aluminum tubing $\frac{3}{4}$ -inch or more in diameter. Increasing the diameter of the tubing increases the surface area of the conductors, thereby increasing the capacitance between the two segments. This changes the L/C ratio. The antenna is resonant with less inductance (L) because it has more capacitance (C). Less inductance (L) results in a lower Q, which gives broader bandwidth. At the same time, capture area is increased and offsets any loss of signal pickup due to lowered Q.

Even broader bandpass can be achieved by means of using, in place of the tubular segments, metal cones or rods arranged in a conical pattern (Fig. 40-3a). But such an arrangement is very heavy. Since the antenna is mounted at the center, it requires strong support. A commonly used modification of the antenna in Fig. 40-3a is shown in Fig. 40-3b. This arrangement which retains much of the conical effect, has a reasonable weight and does not require so strong a support.

Half-Wave Dipole at Frequencies Above Resonance. A dipole can be a half-wave

length ($\lambda/2$) for only one frequency. A number of things happen when the signal frequency is above the antenna's $\lambda/2$ resonant frequency:

1. The inductive reactance across the antenna terminals increases (Fig. 40-4a).
2. The terminal resistance of the antenna increases (Fig. 40-4b).
3. The terminal impedance (vector sum of reactance and resistance) increases.
4. The changed antenna impedance results in a mismatch to the transmission line.
5. The lobe pattern on the graph of the antenna directional response changes.

Notice that the reactance rises gradually (Fig. 40-4a), and then rapidly as the signal frequency approaches twice the $\lambda/2$ resonant

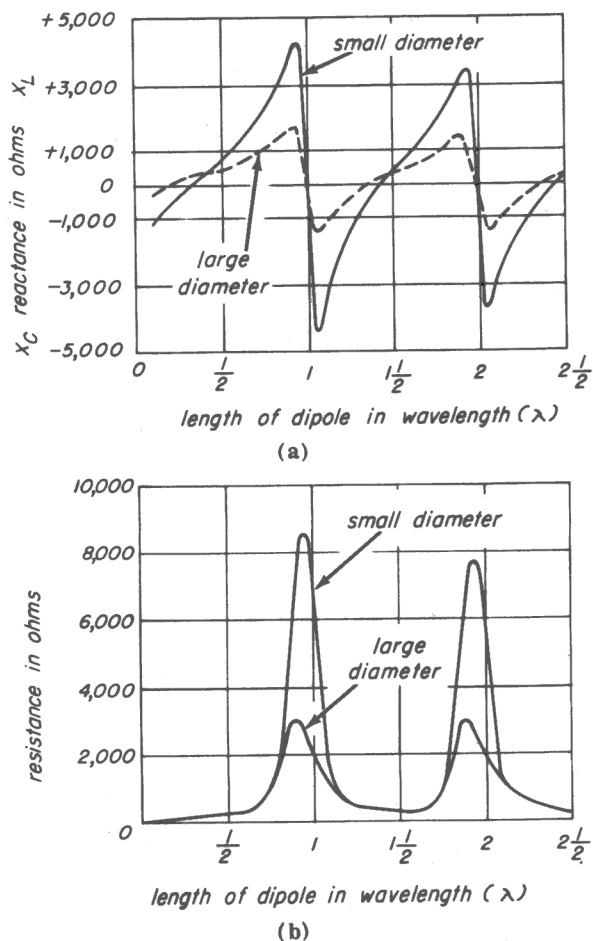


Fig. 40-4

frequency and the antenna becomes one wavelength long. Just before the increasing frequency reaches this one wavelength multiple, the reactance drops sharply and, at the multiple, it is very nearly the same as it was at the $\lambda/2$ resonant frequency. Then it changes its character (shown by negative signs and downward direction of curve) to capacitive reactance, becoming most capacitive at a frequency slightly above the frequency at which the antenna is one wavelength. Thereafter it becomes less capacitive and as the frequency reaches the next multiple (antenna equals $3/2$, or $1\frac{1}{2}$ wavelengths) it changes to inductive again, and the cycle of changes repeats.

Changes in input resistance undergo a similar cyclic variation (Fig. 40-4b). Sharp changes occur at frequencies for which the antenna is close to one wavelength or close to two wavelengths.

Figure 40-4 shows the resistance and reactance variations for two kinds of dipole. One is made of aluminum tubing with a

large diameter; the other is made of wire with a small diameter. The variations are less pronounced for the large-diameter tubing used as an antenna. Its resistance and reactance vary less over the range of frequencies for which the graphs are plotted. This confirms that a dipole having a large diameter is a broad-band antenna; its characteristics are substantially constant for a wide range of frequencies.

Practical television receiver antennas have a fundamental resonant frequency such that higher desired frequencies do not fall close to the even multiples, where the steepest changes in the curves occur. This minimizes impedance mismatch, between antenna and transmission line, at the actual working frequencies. Over the entire TV band the *average* impedance is about 300 ohms. Therefore, 300 ohm transmission line is used and most receivers have 300 ohm input circuits.

Directional Response Lobe Patterns.

When the antenna is working at frequencies that are multiples of its fundamental frequency, the polar coordinate graphs of the directional response lobe patterns are those

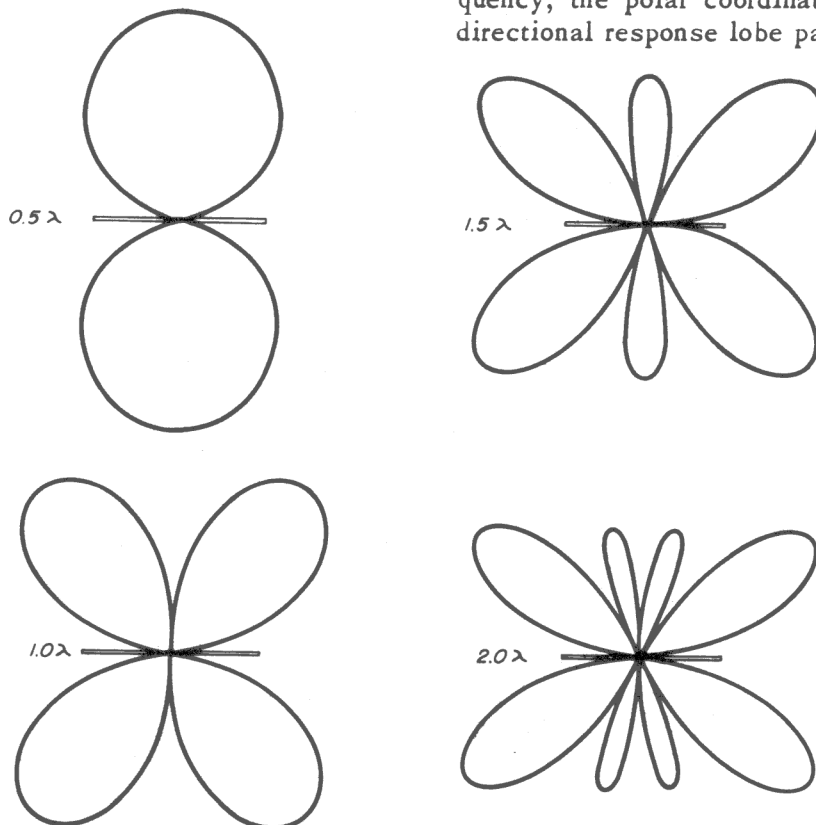


Fig. 40-5

given in Fig. 40-5. Thus at one wavelength the graph shows four major lobes; at $1\frac{1}{2}$ wavelengths it shows six major lobes; at 2 wavelengths it shows four major and 8 minor lobes. Notice that the lobes are like elongated ellipses and that their longest axes are not necessarily at right angles to the dipole. It is important to keep this in mind when orienting the antenna, because, for maximum pickup, it is the long axis of a major lobe that must point to the desired station. For example, if we have a dipole cut to channel 2 (54 to 60 mc) and we wish to favor a weak station on channel 13 (210 to 216 mc), we first note that the antenna is approximately a 2-wave antenna for channel 13. Then we consult the field pattern of a 2-wave dipole and turn the antenna so that one of the pattern's major lobes points toward the weak station. We have a choice of any one of the four major lobes. We select the one which will put the dipole most nearly broadside to the channel 2 station (for which it is a half-wavelength long). Thus we favor channel 13, but we do not seriously discriminate against channel 2.

Folded Dipoles. Aluminum tubing bent into the form shown in Fig. 40-6 constitutes a folded dipole. It has slightly less bandwidth and about the same pickup as the simple dipole, but it has a higher terminal impedance at resonance. It can readily be designed for connection at point X directly to a metal supporting mast without the use of insulating blocks. Contact with the metal mast does not disturb the voltage distribution on the antenna, because point X is at a zero-volts point. The folded dipole is sometimes used as a component of more complex antennas because its high terminal impedance is preferable to the terminal impedance of a simple dipole.

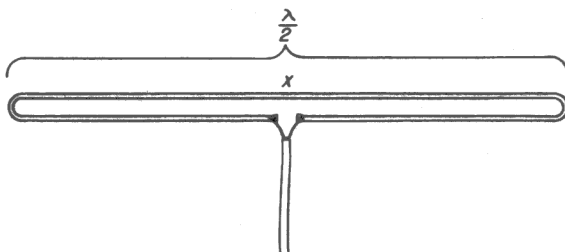


Fig. 40-6

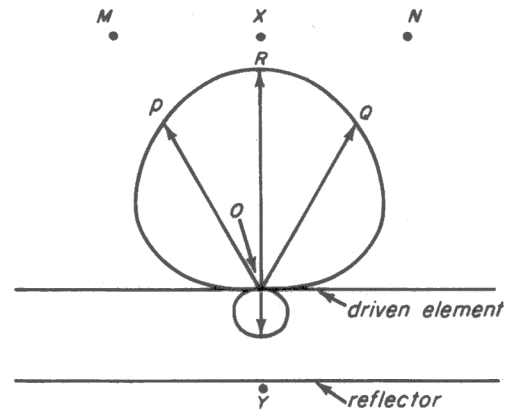


Fig. 40-7

Dipole With Parasitic Elements. The amount of signal picked up by a dipole antenna can be increased and the field pattern can be altered to produce greater directivity if the dipole is accompanied by an additional conductor (a second dipole) not opened at the center and not connected to a load (receiver and transmission line). The second, or *parasitic*, dipole should be parallel to and spaced a quarter-wave or less away from the first, or driven dipole (Fig. 40-7). Since the parasitic dipole, or parasitic element as it is called, has no load to absorb the energy it picks up, it reradiates this energy, acting like a weak transmitter close to the driven dipole. When the spacing between the two elements is just right, the energy from the parasitic element will arrive in phase with the signal directly intercepted by the driven element, and reinforce it. Thus the driven dipole, aided by the parasitic element, collects more energy from space and therefore has a gain over a simple dipole. This principle is used in many complex antennas. Their efficiency is expressed in terms of their gain over a simple dipole. Thus the simple dipole serves as a standard of reference for comparing various antenna types.

Reflectors. If the parasitic element is placed on the side of the dipole away from the received station, the element is called a reflector. Experiment has shown that more reradiated energy is transferred to the driven element if the reflector is moved closer to the driven element than it should be for proper phasing when both elements are of equal length. Increased length cor-

rects the shift of phase between elements caused by decreased spacing. Maximum energy transfer occurs when the spacing is about 0.15 wavelength and the reflector is 5 percent longer than the driven element.

At the same time that the gain of the dipole is increased by the addition of a reflector, the directional lobe pattern is also favorably altered. The lobe on the side of the dipole towards the station is enlarged; the lobe on the far side of the dipole, or driven element, is greatly reduced (Fig. 40-7). Now the antenna picks up much more signal coming from the direction X than from the direction Y . The side of the antenna facing X is considered to be the front and the side facing Y is considered to be the back. Since the antenna picks up much more signal from the front than from the back, it is said to have a high front-to-back ratio.

Directive antennas are said to have a beam width, since they not only picked up stations coming from precisely the direction X , but they also have considerable pickup for stations on either side of X , such as M and N . If we call the center of the driven element O , the strength of signal picked up from direction X is represented by the length of the arrow OR . The strength of the signals picked up from the directions M and N are represented by the lengths of arrows OP and OQ . Let the length of arrow OR be considered unity, or 1. Let the signals from M and N be precisely as strong and (for the sake of illustration) of the same frequency as that from X , so that the only reason arrows OP and OQ are shorter than arrow OR is that signals from M and N do not arrive from a direction broadside to the driven element, and the antenna does not pick up as much of their energy. When the directions of M and N are such that arrows OP and OQ are 0.707 times as long as arrow OR , the angular width of the beam of satisfactory reception (or propagation) is the angle POQ .

Directors. Another parasitic element can be placed near the dipole on the front side. An element placed in front of the driven

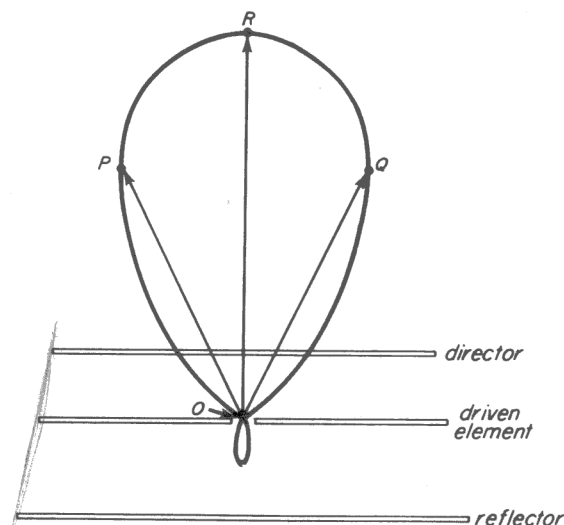


Fig. 40-8

element is called a director (Fig. 40-8) and is made slightly shorter than the driven element. If the rear element — the reflector — is regarded as a sort of electrical mirror, the front element — the director — may be regarded as a sort of lens. Both concentrate the incoming beam on the driven element, which therefore collects more energy.

The added element still further increases the directivity of the antenna. With three elements — reflector, driven element, and director — the field pattern of the antenna is that shown in Fig. 40-8. Note that the front, or main, lobe has changed to an elongated form. Now when OP and OQ are drawn so that they equal 0.707 times OR , the angle they form, POQ , is much narrower than it was before the director was added.

Yagi Antennas. Still more directors can be added in front of the antenna. Each new director increases the gain and decreases the beam width. The antenna tends to pick up stations straight ahead (in line with arrow OR) and reject, or offer little pickup, to stations outside the angle POQ . An antenna with many elements has a very narrow beam width and high gain to those stations straight ahead and at the resonant frequency for which it is cut. Such a multi-element antenna (Fig. 40-9) is known as a Yagi antenna, after the Japanese scientist who developed it.

Added elements not only decrease beam width: they also decrease bandwidth. A

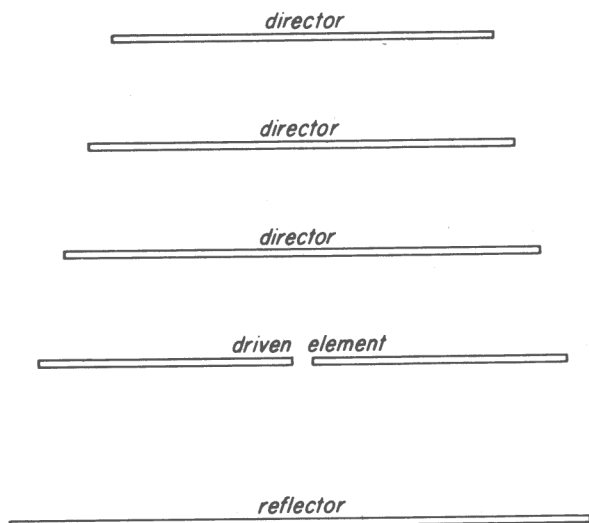


Fig. 40-9

multielement Yagi is not suited for covering the entire TV band. It is essentially a one-channel antenna — its directional response and its frequency response are both narrow. Additional elements also decrease the terminal impedance of the antenna, since each element is effectively in parallel with the driven element (coupled to the driven element by the electromagnetic field). Yagis therefore present problems in matching antennas to transmission lines. A multielement Yagi may have a terminal impedance as low as 10 ohms. A folded dipole is often used as the driven element in Yagis because its relatively high impedance helps to raise the over-all impedance.

After one reflector has been added, extra reflectors do not provide significant improvement. In this respect, they differ from directors. Consequently, Yagis usually have only one reflector. Reflector and directors are normally mounted with their centers directly connected to the supporting rod that holds all the elements in place. The supporting rod does not impair the effect of reflector and directors, because it connects to them at a zero-volts point. The driven element, if not a folded dipole, is usually supported by insulating blocks at its center. The insulating blocks are secured to the supporting rod.

Many modifications of the Yagi antenna exist, including a few that have broad enough bandpass to cover the low VHF band or the high VHF band. Modifications in-

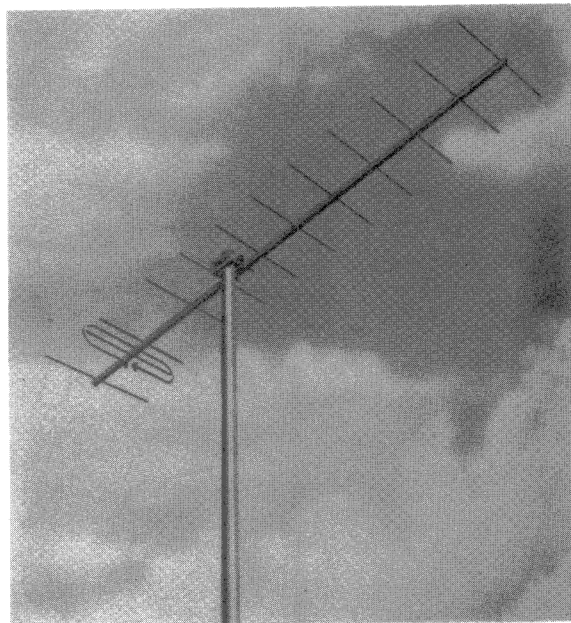


Fig. 40-10

volve departures from the basic Yagi, such as using two or more driven elements of different length, spaced apart to give special phase relationships; and having special spacing and lengths for the reflector and directors. These are fringe area antennas, designed to give practical bandwidth with exceptional gain. For a given number of elements, the basic Yagi provides higher gain, but the usable bandwidth is confined to one channel. The best commercial modifications achieve a large increase in bandwidth with only a small sacrifice in gain. A version designed for fringe area coverage of the UHF band is shown in Fig. 40-10.

An arrangement of a dipole with one or more additional elements is called an *array*. In fringe areas where maximum gain is needed, two similar arrays, mounted one above the other on the same mast, are frequently used. The arrays are then said to be *stacked*. The way in which the arrays are spaced and connected to the common transmission line causes their signals to be in phase and, therefore, reinforce each other. The system is not limited to two arrays. Three or more arrays may be stacked. Each added array is equivalent to an increase in the capture area of the antenna. A popular commercial antenna, a conical dipole with a reflector is shown in Fig. 40-11a.

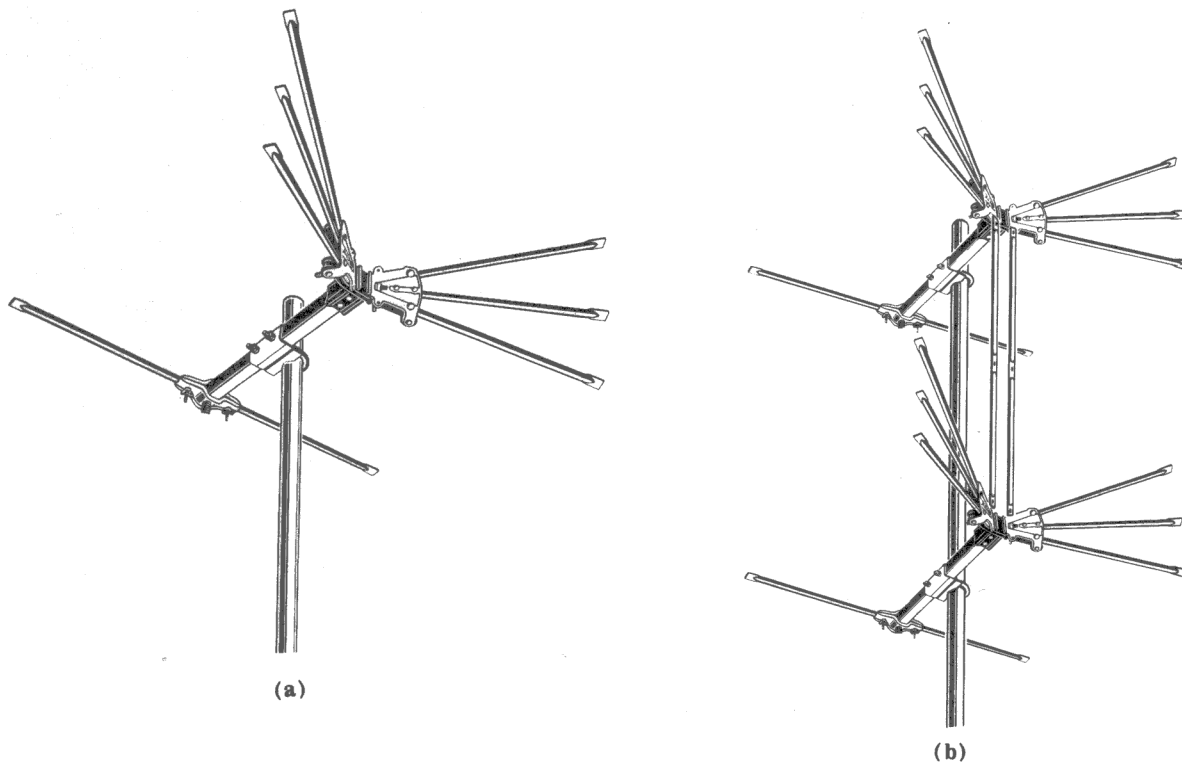


Fig. 40-11

A stacked version of the same antenna is shown at *b*.

High-Band, Low-Band Combination. The antenna shown in Fig. 40-12 consists of a high-band VHF antenna and a low-band VHF antenna connected through a phasing harness to a common transmission line. (It is not a stacked array, because the upper and lower arrays are dissimilar.) The phasing harness consists of carefully chosen lengths of transmission line, using the effects of high impedance and low impedance at different points along the harness to isolate each antenna at the operating frequency of the other. Thus, neither an-

tenna loads the other or disturbs its directivity pattern. At an appropriate point on the harness, the signals from both antennas are routed through a junction block to the main length of the transmission line going down to the TV receiver.

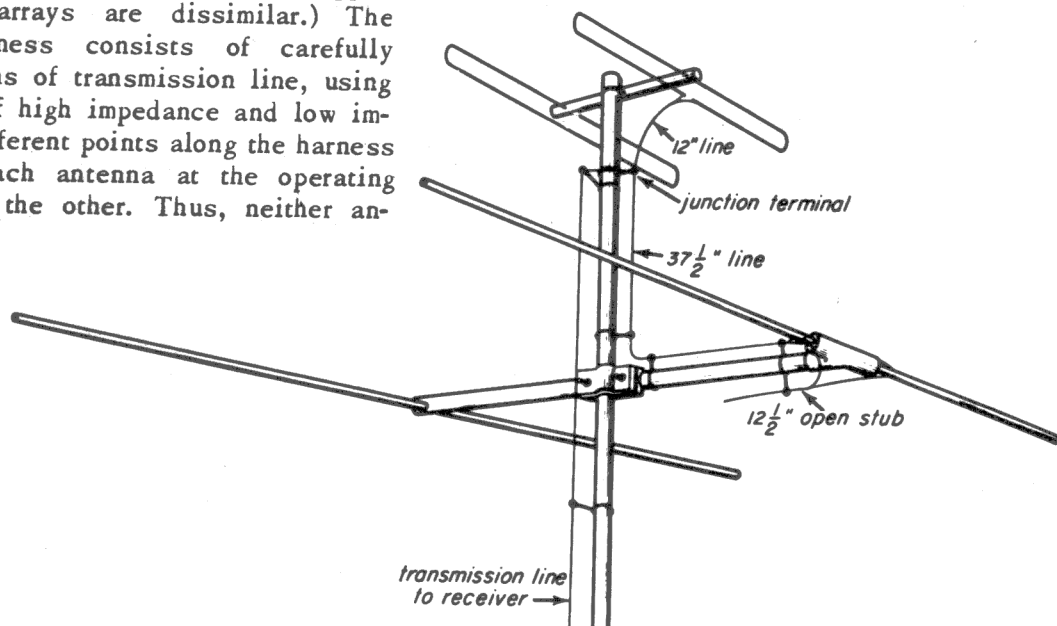


Fig. 40-12

The advantages gained by using separate high and low band elements in this way are:

1. Each element can be separately oriented in case high band stations are located in a different direction from low band stations.

2. Each element can enjoy added gain and good front-to-back ratio afforded by a reflector.

3. Each element can be cut for optimum response in its portion of the VHF spectrum.

Good front-to-back ratio is an important factor in locations where ghosts, arriving from the rear, are common, as in hilly terrain, or in large cities with many tall buildings. Optimum response on both high and low bands makes the antenna satisfactory for use at considerable distances from the transmitter, so that it is a good near-fringe-area antenna.

V Antennas. When a wire is considerably more than a half-wave in length — for example, when it is two waves long — the field pattern has major lobes that are not at right angles to the wire (Fig. 40-5). If two such wires are arranged in a V having the proper angle, two major lobes around each wire will be parallel to the two corresponding major lobes around the other wire, as shown in Fig. 40-13a. These lobes will be in phase and will reinforce each other, while the remaining lobes being of nearly opposite phase, will largely cancel. As a consequence, a bidirectional response exists, as shown at b.

The V antenna can be given a unidirectional response, with good front-to-back ratio if two V elements are used so that one serves as a reflector for the other. A popular commercially made version of such an antenna is shown in Fig. 40-14. The reflector does not have to be parasitic. It may be driven (connected to the transmission line). But in this arrangement it must be spaced an odd number of quarter-wavelengths from the front element, in order that it may be driven 90 degrees out-of-phase with the

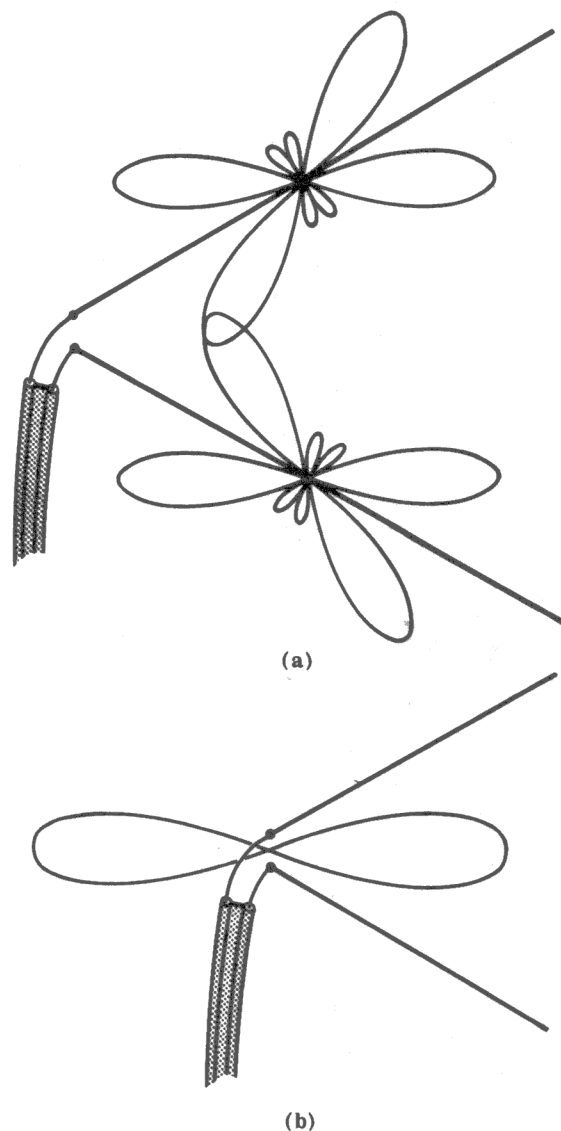


Fig. 40-13

front element. It is the 90-degree phase difference that makes the field pattern unidirectional.

In the version shown, the front and rear elements are connected to each other, not by transmission line but by the aluminum tubing of which they are made. The two halves of the antenna are held in alignment by strong insulating blocks.

When correctly oriented, the open end of the V points toward the station whose signal is being received.

Conical V-Antenna. Conical antennas may be bent forward in shape of a V (Fig.



Fig. 40-14

40-15). The conical configuration results in improved bandwidth. The V shape provides single lobe directional response on high VHF channels.

Fringe Antennas. At distances greater than 40 or 50 miles from the transmitter, television reception demands utmost performance from the receiving antenna. The highest possible gain is needed in order to provide good signal-to-noise ratio. In practically all the designs the required gain is achieved by using one or more half-wave dipoles, together with parasitic elements. Multielement arrangements have large capture area and concentrate the intercepted signal on the dipole, as exemplified by the Yagi antenna. The narrow bandwidth that characterizes the straight Yagi is overcome primarily by manipulating the spacing, length, and relative phasing of the elements; by using different diameters of tubing for

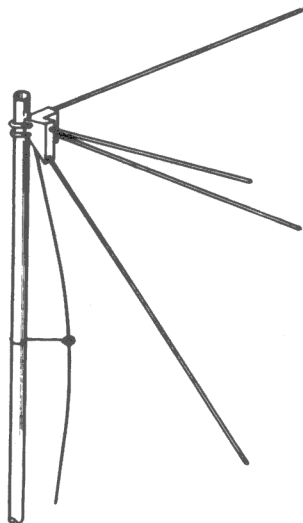


Fig. 40-15

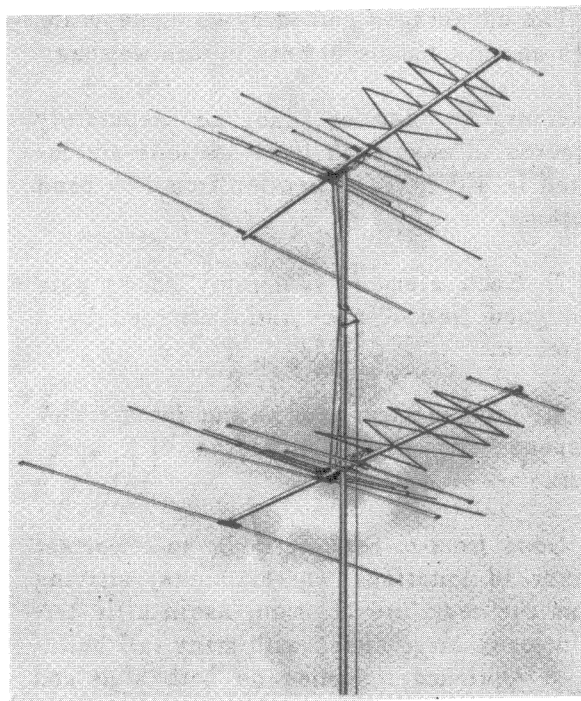


Fig. 40-16

different elements; by using slanted and curved elements; and by using two or more dipoles resonant at different frequencies.

A popular antenna designed for *deep fringe* areas — areas of extremely low signal strength — is shown in Fig. 40-16. Note the varied diameters, lengths, slants, and spacing of the elements. Note that the arrays are stacked and that the transmission line takes the signal off at a point midway between the two arrays. This ensures that the signals supplied to the line by each array will enter the line exactly in phase.

Indoor, or Rabbit-Ears Antennas. When the receiver is located close to a transmitter an outdoor antenna is often unnecessary. Satisfactory reception is possible with the familiar type of antenna shown in Fig. 40-17. The side pieces are really the quarter-wave sections of a half-wave dipole, folded upward to form a V standing on its point. They consist of telescoping tubing, so their length may be adjusted for resonance at the frequency of the carrier being received. Narrowing or widening the angle of the V alters the impedance of the antenna; therefore, it can be matched closely to the transmission line and provide

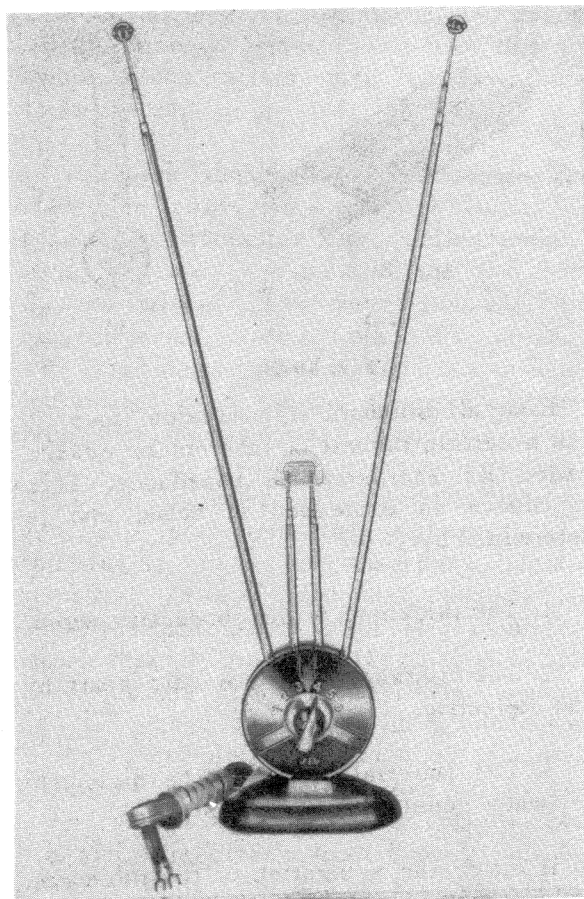


Fig. 40-17

efficient energy transfer. Improved contrast is afforded by the adjustable stub in the center, which enables the user to eliminate any reactive component of the antenna's impedance that might cause line reflections and loss of energy.

Also, it may be possible to use the switch when changing channels rather than to lengthen or shorten the elements or to turn the assembly. However, the numbers on the switch do not refer to channel numbers.

The antenna shown in Fig. 40-17 is one of a number of rabbit-ear designs. In the simplest form, no switch is provided. Often portable receivers are equipped with rabbit ears that telescope into a housing mounted on the rear of the cabinet for convenient storage. These units may be purchased separately and installed on any receiver. The antenna of Fig. 40-17, may be grasped by the base (insulating material) and rotated for best orientation on each station. It has a one-to-one front-to-back ratio and, there-

for, does not discriminate against ghost signals arriving from the rear. Reception may be disturbed by a person touching the elements or even standing near the antenna. The metal of the elements should not be handled during adjustments.

40-3. FM RECEIVING ANTENNAS

Because the FM receiver is unresponsive to amplitude variations, it can produce a noise free output from signals of just a few microvolts. It does not require as favorable a signal-to-noise ratio as a television receiver. Consequently, FM antennas are rarely as complex as TV antennas.

Most manufacturers recommend a simple folded dipole as a suitable FM antenna. It can be conveniently made from ordinary 300-ohm line, as shown in Fig. 40-18. A length of the flat line is cut to be a half-wave long at a frequency near the middle of the FM band. At each end of the section, a half-inch of each conductor is exposed by stripping the insulation. The exposed ends are twisted together as shown and soldered. Then at the center of the section, one conductor is cut, and the two ends thus made are exposed by stripping, as shown. A piece of the same kind of line, long enough to serve as a lead-in to the receiver, is spliced as shown and soldered. Such an antenna may be located out of sight in a closet, in an attic, or even under the rug if the receiver is within a few miles of the transmitter. If it is required to receive distant or weak stations, it should be located high above the ground, and, if possible, clear of surrounding objects. It should

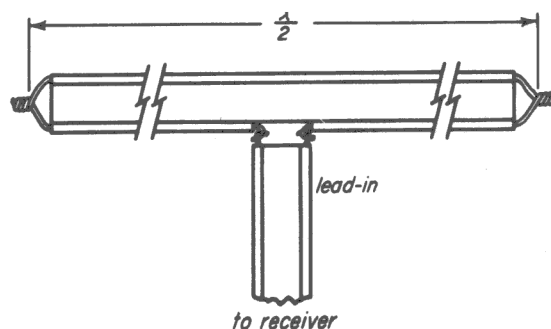


Fig. 40-18

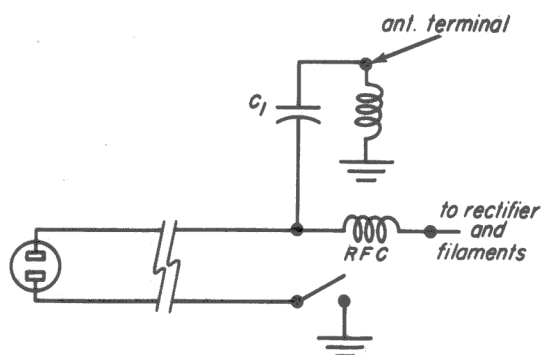


Fig. 40-19

not be tacked against a plaster wall. Plaster walls retain moisture which would greatly reduce the pickup.

In areas remote from FM stations, a folded dipole of aluminum tubing (with or without a reflector) will provide much greater pickup. It should be high above ground and correctly oriented.

In areas very close to powerful FM transmitters, as in large cities, the line cord of the receiver is often a satisfactory antenna. A capacitor of just a few microfarads is connected between an appropriate antenna input terminal and one end of the line in the receiver — not the end that connects to ground in a-c/d-c receivers. The end of the line used for signal take-off is isolated from other parts of the receiver by an r-f choke, to prevent r-f energy from having a low-impedance path to receiver ground through filament string, rectifier, or other route (Fig. 40-19).

Where the line-cord antenna is inadequate and where the other types are unsuitable (because of appearance, or no handy place for mounting) a rabbit-ears TV antenna provides good FM reception.

40-4. TRANSMISSION LINES

The most common type of transmission line used in TV antenna installations is a flat ribbon of tough dielectric material containing flexible stranded wires imbedded in the dielectric at its edges. This is illustrated in isometric view and in cross-section in Fig. 40-20.

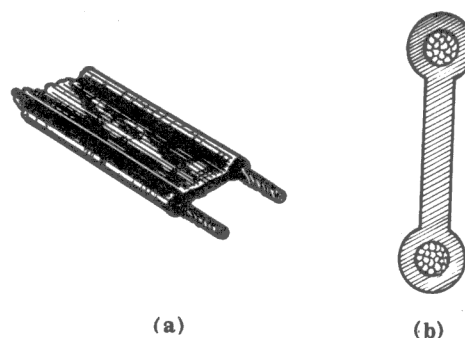


Fig. 40-20

Like all standard transmission lines, it has a certain natural or inherent impedance called its *characteristic impedance*. This impedance is expressed in ohms, and is determined by:

1. The thickness of the conducting wires.
2. The distance they are held apart by the dielectric.
3. The material of which the dielectric separator consists (usually a plastic).

If either the separation or the thickness of the wires is altered, the characteristic impedance of the line is changed. If a different dielectric material is used, the characteristic impedance of the line is changed. The characteristic impedance of the line does *not* change with length of the line.

The transmission line connects the receiving antenna to the TV receiver. The antenna is a source of signal power, and the receiver is a load upon the source. If the antenna has a terminal impedance of 300 ohms, and if we can connect it directly to the input terminals of the receiver, we need a receiver whose input circuit has an impedance of 300 ohms in order to match the antenna impedance and get maximum transfer of energy. But with the antenna on the roof and the receiver downstairs, they cannot be connected together directly. We must have something between them that matches both — namely, a length of transmission line. If the characteristic impedance of the line is also 300 ohms, it will be matched to the antenna and will be able to absorb maximum output from the antenna. At its lower end it will be

matched to the 300-ohm input of the receiver; the receiver will be able to absorb all the energy coming down from the antenna, minus certain small losses not due to mismatch.

Coaxial Transmission Line. Besides the flat-ribbon twin-lead line, there is another type of transmission line, called coaxial line, because the axes of the two conductors coincide. This means that one conductor must be within the other (Fig. 40-21a). The inner conductor is usually a thin wire, surrounded by a tubular plastic (polyethylene) insulating separator. Over this plastic tube, a close-woven mesh of fine wire forms the outer conductor. The outer conductor is generally protected from moisture by a tight-fitting layer of waterproof plastic (vinylite). In use, the outer conductor is usually connected to a receiver input terminal that is grounded (Fig. 40-21b). No noise pulses or other interfering signals can be picked up by the inner conductor, which is completely shielded by the outer conductor. Any signals picked up by the outer conductor are applied to the grounded end of the receiver's input loading coil instead of to the hot end of the coil. Thus, little or no signal is picked up on the line; the line merely conducts signals, picked up by the antenna, to the receiver. Coaxial line is preferred for installations where the line must pass close to sources of high level noise, since coaxial line is more immune to noise pickup than twin lead line.

Many receivers have input circuits that will match either 72-ohm coaxial line, or

300-ohm twin-lead line. A simple way of accomplishing this dual match is shown in Fig. 40-21c. The coaxial line would be connected across X and Y , or the twin lead would be connected across X and Z .

Propagation Velocity Factor (PVF) in Transmission Lines. In an earlier lesson you learned that the velocity (speed of travel) of a wave in the wire of an antenna is less than the velocity of a wave in free space. Therefore a wavelength in wire is shorter than a wavelength in space. This effect is very pronounced in transmission lines, due to the added influence of the dielectric material and the effect the conductors have upon each other as a result of their closeness. Due to retarded velocity, the length of a wave (distance the electric impulse travels in one cycle) is shorter than in free space. The length of the wave in a wire or a transmission line is called its electrical wavelength. If we take the velocity of the wave in space as unity, or 1, the velocity in standard transmission line may be as little as 0.68, about two-thirds the space velocity. The number 0.68 is called the propagation velocity factor, or PVF. It is different for different types of line. It varies with the characteristic impedance, Z_0 . Then PVF for standard lines of various characteristic impedances (Z_0) is given in Table A. (Attenuation of the signal per hundred feet of line is also given. This is a measure of line losses which will be discussed presently.)

The PVF may be used as follows. Suppose that a certain signal has a wavelength

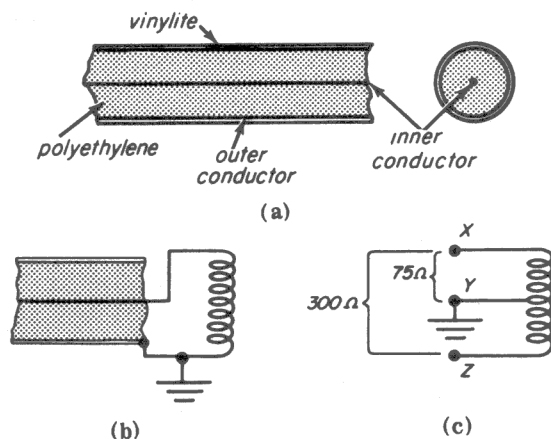


Fig. 40-21

TABLE A					
ATTENUATION IN DB PER HUNDRED FEET					
Z_0	PVF	50 mc	90 mc	170 mc	200 mc
75	0.68	2.3	3.6	5.7	8.4
150	0.77	1.5	2.5	4.0	4.6
300	0.83	1.05	1.5	2.1	2.3
300*	0.83	0.85	1.2	1.7	1.82

* Special tubular type

of 100 inches in space and we want a section of 300-ohm line that will be a quarter-wave long for that signal. First we calculate a quarter wavelength in space. It is 25 inches. Then we look up the *PVF* for 300-ohm line and find it to be 0.83. We multiply 25 by 0.83, and get 20.75 inches. The section of line must be 20.75 inches long.

Transmission Line Losses. The wires that serve as conductors in transmission lines have a small amount of d-c resistance per hundred feet of line. In addition, the high grade insulating and separating material that holds the wires accurately spaced is a good, but not a perfect, insulator. It has the unavoidable effect of connecting a very high, but still undesirable shunt resistance across the gap separating the wires. Thus, r-f energy applied to the line is partially dissipated in series and shunt resistance.

In addition to d-c resistance losses, r-f energy is also wasted in a special kind of a-c resistance known as skin effect, discussed in an earlier lesson. At high radio frequencies, the current tends to travel mainly through a thin layer, or skin, at the surface of the conductors. This reduces the effective thickness of the wire through which the current can travel. Therefore, as far as the current is concerned, this amounts to an increase in the resistance per unit of wire thickness. The higher the frequency, the more pronounced the skin effect.

Moreover, r-f current alternations cause the molecules of the dielectric separator to vibrate rapidly, and this uses up some of the r-f energy, which is dissipated as heat. In rainy weather, when the ribbon line is wet, this effect is increased because the water uses up r-f energy similarly but to a greater extent than the dielectric material. All these effects, which have nothing to do with mismatch, waste r-f energy between the antenna and the receiver.

When antenna installations are made in a large city near the transmitters, these losses can be ignored because there is generally signal strength to spare. But for fringe area installations, line losses must

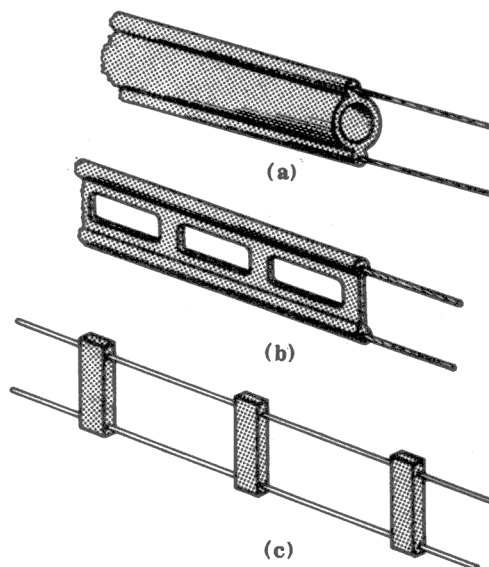


Fig. 40-22

be taken into account. To keep line losses at a minimum, special types of transmission line are used. Three common types are shown in Fig. 40-22a, b, and c. The tubular type at *A* ensures that only air, and not water or dielectric material, can occupy the space directly between the conductors, where the fields around the conductors are densest. The flat line, shown at *b*, with the punched-out rectangular windows, retains the convenient, easy-to-handle ribbon shape, while reducing the amount of dielectric material between the conductors. In rainy weather, however, the windows tend to fill with a film of water, and the advantages of the construction are temporarily lost. The type of line shown at *c* is called open line. Small plastic bars, spaced at regular intervals, keep the conductors separated and parallel. This line has the lowest loss, and is used where very long runs between antenna and receiver are unavoidable, as from a hilltop to a house in the valley.

Terminated Lines. When the terminals of a 300-ohm line are connected to a receiver whose input circuit has an impedance of 300 ohms, no mismatch exists between line and receiver. The line is said to be *correctly terminated*. This is another way of saying that the r-f energy flowing in the line finds a load at the end that can absorb all the energy the line can deliver. Under these conditions, the load appears to the line as though it were a 300-ohm resistor.

But when the input circuit of the receiver has an impedance different from that of the line — for instance, when the line impedance is 300 ohms and the receiver's is 72, or when the line impedance is 72 ohms and the receiver impedance is 300 — the line is not efficiently or correctly, terminated. The load now cannot absorb all the energy the line delivers. The portion of the delivered energy not absorbed is reflected back along the line.

Ghost Images Due to Line Reflections.

At a frequency for which the antenna is mismatched to the line, and the receiver is also mismatched, the energy reflected back up to it from the mismatched receiver load will be reflected again, due to antenna mismatch, and will be returned down the line to the receiver. A portion of it will be accepted by the receiver's input circuit, and will be reproduced as picture information on the TV screen. But the picture information due to the rereflected energy will appear on the screen a fraction of a second after the picture information due to the original signal. The moving spot of light that *paints* the picture on the screen when modulated by the signal will have moved appreciably during the time the twice-reflected energy went up and down the line. The image portions due to the reflected energy will not be superimposed on those due to the original non-reflected energy. Consequently, there will be two images, one of them a *ghost* of the other. Unlike ghosts due to reflections from buildings and other objects — ghosts actually picked up by the antenna — transmission line ghosts cannot be eliminated by orienting the antenna. They are due to double mismatch, a condition that is not changed by orienting the antenna.

Note that line ghosts require two reflections. If the receiver is matched to the line, the antenna may be mismatched; and yet no line ghosts will result, since reflection can occur only at the one mismatched end of the line. But the matched end sends no signals up to the mismatched end to be rereflected. Therefore, the mismatched end has no ghost-making effect.

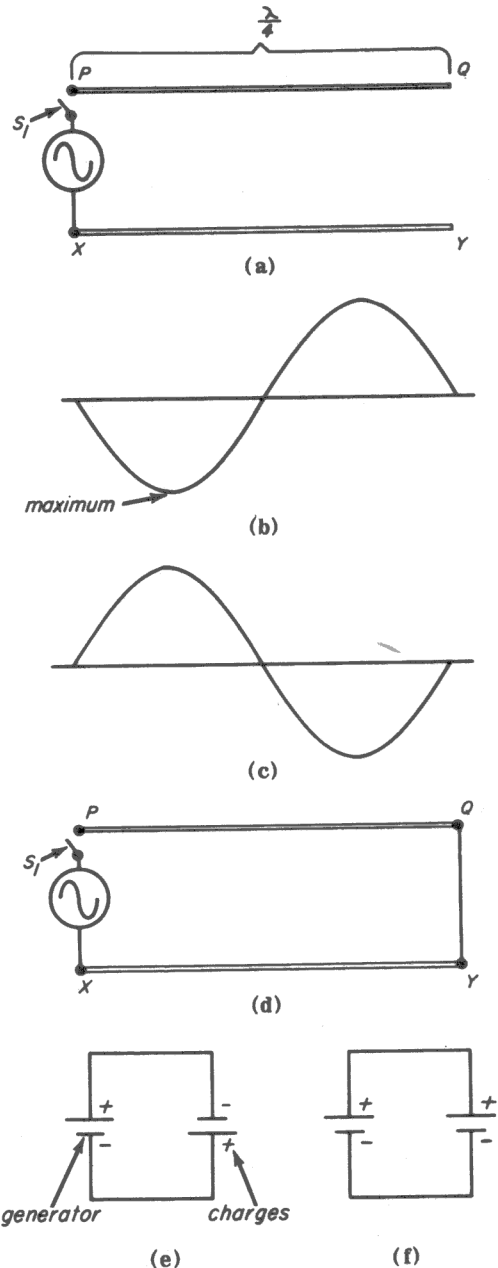


Fig. 40-23

Transmission Line Fragments as Resonant Circuits. When a length of transmission line is just a quarter-wave long, it has some surprising properties. If an r-f generator, operating at the frequency for which the line is a quarter-wave long, is connected to one end, you might think that the line would appear as an open circuit and not load the generator at all. Just the contrary is true. The quarter-wave section behaves like a series resonant circuit, equivalent to a very low impedance short that draws a heavy current from the gener-

ator. The generator *sees* the far end as though it were shorted. This behavior can be understood by referring to Fig. 40-23a. The conductors PQ and XY are each electrically one quarter-wave in length. The generator is producing a sine wave signal, one cycle of which is shown at *b*. This is the voltage it will apply to point P . The voltage it will apply to point X is opposite in polarity, as shown at *c*. For the sake of simplicity, let us suppose that switch S_1 is closed just at the instant when the upper terminal of the generator is at maximum negative potential and the lower terminal is at maximum positive potential. A charge corresponding to maximum negative potential will move along the upper conductor from P to Q . At Q it will be reflected back toward P . Two quarter-cycles, or one half-cycle, after leaving P it will reach P again. But in the interval, the generator has gone through a half-cycle, and its upper terminal is now at maximum positive potential.

In similar fashion, and during the same half-cycle interval, a charge corresponding to maximum positive potential leaves point X , moves along the lower conductor to point Y , is reflected, and reaches point X again just as the lower terminal of the generator reaches maximum negative potential.

During the half-cycle interval the charges have retained their original polarity and most of their original potential. But the generator has reversed its polarity. Let us now represent, by batteries, the difference of potential across the generator and the difference of potential between the charges as they are at the instant of their return to their starting points. These equivalent batteries, marked *generator* and *charge* are shown at *e*. Note that they are connected in series and that the circuit is closed. This is the condition for maximum current flow in the circuit.

Thus we can see that because of its length, the reflected voltages on an open quarter-wave section of transmission line return to the source just in time to load the source with a *battery* or energy of opposite polarity. To the source, this is equivalent

to a short across the terminals, for it draws a heavy current from the source.

If the switch S_1 had been closed at some point in the r-f cycle other than maximum negative or positive potential, the reflected voltages would still return to their starting point one-half cycle later and find the potential of their source equal, and of opposite polarity, to themselves. That is, once the first half-cycle is completed, the source is continuously loaded by the returning charges and *sees* a steady short, as if it were feeding into a series resonant circuit, or other very low-impedance load.

Suppose now that we actually do short the the open end of the quarterwave section by connecting points Q and Y together, as shown at *e*. Now another surprise occurs; the short seen by the generator disappears. The generator now sees an open circuit. This can be explained as follows. When S_1 is closed, a charge moves from point P to Q . But Q is not an open end now. The charge has somewhere to go, and is not reflected back along the same conductor on which it arrived at point Q . It continues on through Y towards X , arriving at X one half-cycle after leaving P . If point P was at maximum negative potential when the charge started out, point X will be at maximum negative potential a half-cycle later when the charge arrives at X . Similarly, a positive charge leaving X at the moment S_1 is closed goes via Y and Q to P , arriving as P becomes positive. As before, the charges retain their polarity while the generator reverses its polarity during the half-cycle. If we now represent the potential difference between the generator terminals and the potential difference of the charges by equivalent batteries, we find that the batteries are as shown at *f*. No current flows from either one to the other. Neither one is loaded by the other.

Under these conditions, the generator sees an open circuit or a very high impedance parallel resonant circuit across its terminals.

If, instead of shorting Q and Y together, we double the length of the section, making it a half-wave section of transmission line with an open end, the generator will see

this as an open circuit, or very high impedance parallel resonant circuit. This is true because a charge, going from *P* to *Q* and back to *P* again now requires a whole r-f cycle. During this time, the generator goes through a whole cycle, and has its original polarity when the charges return to their starting point. The equivalent batteries are the same as for the quarter-wave shorted stub and the source is not loaded. The generator sees an open circuit across its terminals. This is just the opposite of what the generator saw when the open line was only one quarter-wave long.

If we make the section of open line three quarter-waves long, the generator will again see the far end as a short. If we make it four quarter-waves long, the generator will see an open circuit again. In other words, with each added quarter wavelength, the impedance seen at the far end of the line reverses, that is, goes from high to low, or vice versa. It also reverses every quarter wavelength if we actually short the conductors at the far end.

In addition to the foregoing properties of quarter-wave sections, and multiples thereof, lengths of line slightly less, or slightly more than a quarter-wave, appear to the generator, not as open circuits, or short circuits, but as capacitances or inductances. The relationships are summed up in the following Tables B and C.

Quarter-Wave, or Half-Wave, Stub for Suppressing Interference. A practical application of a resonant fragment or stub of transmission line is to short out an interfering carrier signal. Sometimes a station on one

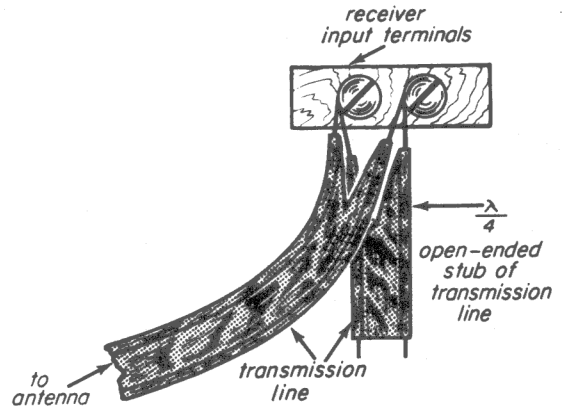


Fig. 40-24

channel supplies a signal so powerful at the receiver input that it overdrives the r-f amplifier tube, even when the receiver is tuned to another channel. If an open-ended quarter-wave stub is cut to the frequency of the offending signal, and if one end is then connected across the lead-in line at the receiver input terminals (Fig. 40-24), the offending signal will see this stub as a low-impedance short across the terminals; the signal will be greatly attenuated by the stub. It will be unable to produce visible interference. The desired signal, for which the stub is not series-resonant, will not be greatly attenuated.

Sometimes, in practical work, a half-wave stub with the far end shorted (equivalent in action to an open quarter-wave stub) is connected across the receiver's input terminals. An open-ended quarter-wave stub is easily detuned if its position with respect to chassis, etc., is altered slightly, whereas the half-wave stub is more immune to changes in position relative to other objects.

TABLE B	
FAR END OF SECTION LEFT OPEN	
Length	Generator Sees As
Less than a quarter-wave	A capacitance
More than a quarter-wave	An inductance

TABLE C	
FAR END OF SECTION SHORTED	
Length	Generator Sees As
Less than a quarter-wave	An inductance
More than a quarter-wave	A capacitance

The Transmission Line Balun. The word *balun* is made up of the first few letters (*bal*) of the word *balanced* and the first two letters (*un*) of the word *unbalanced*. *Balun* describes a device connected between the ends of a 72-ohm coaxial transmission line lead-in (an unbalanced line) and the input terminals of a receiver designed to terminate a 300-ohm parallel-wire transmission line (a balanced line) as shown in Fig. 40-25. The balun serves two purposes:

1. The balun converts the single phase signal at point *A* that is carried on the unbalanced line and changes it to a two-phase signal shown at point *B* of the kind carried on balanced lines.

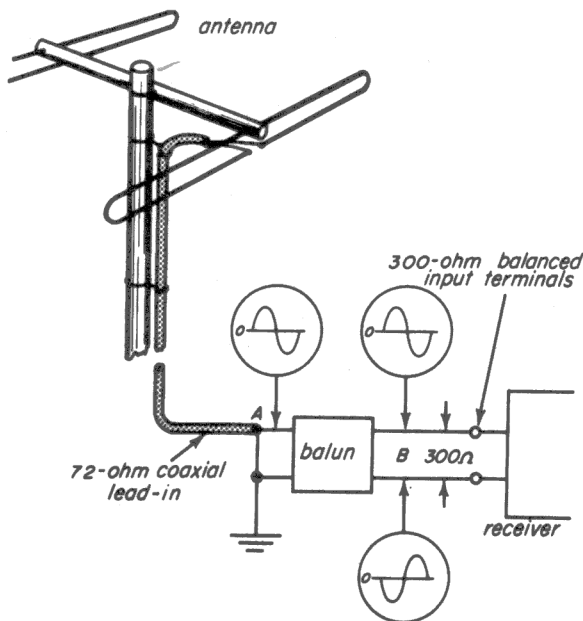


Fig. 40-25

2. The balun terminates the 72-ohm lead-in in 72 ohms when the balun is terminated by the receiver in 300 ohms.

A half-wave ($\lambda/2$) stub of 72-ohm coaxial cable can be used to make a balun as shown in Fig. 40-26. Let us trace the reasoning that leads to the circuit of Fig. 40-26. To begin, suppose that you have a $\lambda/2$ stub of 72-ohm coaxial cable, one end of which is terminated in a 150-ohm resistor (Fig. 40-27a). The line is terminated in a mismatch. The instantaneous voltage and current that exists at any point on a mismatched (resonant) line also exists at another point $\lambda/2$ distant. Therefore, the voltage and current at the terminals of the $\lambda/2$ stub where the 150-ohm

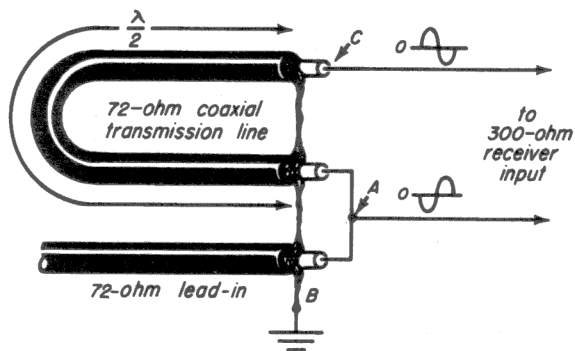


Fig. 40-26

resistor is connected repeats at the open terminals at the other end of the stub. That is, the *values* of voltage and current at the open end (terminals *A* and *B*) of the stub are what they would be if a 150-ohm resistor were connected. (The phase of voltage and current is reversed; that is, changed by 180° .) The impedance across terminals *A* and *B* is the impedance that exists across a 72-ohm line where a 150-ohm resistor is across it. We can say that *looking into terminals A and B*, we see a 150-ohm resistor. If you connect an actual 150-ohm resistor across *A* and *B* (Fig. 40-27b), the actual 150-ohm resistor is in parallel with the 150-ohm resistor that *we see*. Now looking into terminals *A* and *B*, we see 75 ohms. If, as shown in Fig. 40-27c, a 72-ohm coaxial lead-in is terminated in the resistor-loaded stub of Fig. 40-27b, the lead-in will be impedance matched. (A 72-ohm line terminated in 75 ohms is considered matched for practical purposes.) Observe that the total resistance of the load resistors as measured between terminal *A* and terminal *C* of Fig. 40-27c is 300 ohms. Therefore, the two resistors can be replaced by a properly terminated 300-ohm balanced line and the 72-ohm lead-in will still see 75 ohms across terminals *A* and *B*. The 72-ohm lead-in will be terminated in 75 ohms when the balun is terminated in 300 ohms. If you compare Fig. 40-27 with Fig. 40-26, you will see that the coaxial circuits in the two figures are identical. To aid in the comparison, terminals *A*, *B*, and *C* are marked on both figures. Both figures depict the same balun. The circuit is usually drawn as in Fig. 40-26.

Having reasoned that the balun terminates the coaxial lead-in in 75 ohms when the ba-

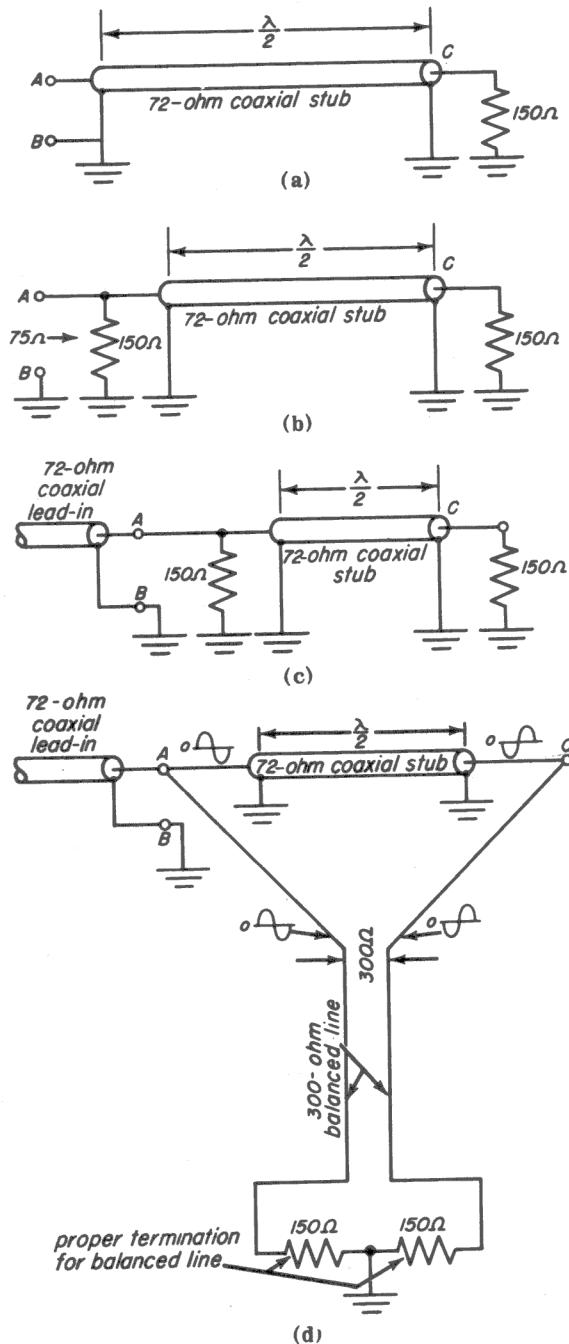


Fig. 40-27

lun is terminated in 300 ohms, we must now examine the circuit to find out if the phase of the traveling wave is as it should be. The phase of a wave on one wire of a balanced line should be reversed 180 degrees

compared to the other wire. Since the two wires of the balanced line connect at terminals A, and C, the phase at C should be reversed 180 degrees compared to A. This is so because a wave traveling on a transmission line reverses phase every half wavelength on the line. The wave is, in fact, an a-c voltage (or current) that is both traveling on the line as an impulse and varying in magnitude (instantaneous voltage value) and polarity. It reverses polarity (a 180 degrees phase reversal) every one half cycle in time. In that time, the impulse travels one half wavelength on the line.

So the phase relationships (shown in Figs. 40-25, 26, and 27) are as they should be. However, to be balanced, the wave voltages must be equal as well as out of phase. The a-c voltages at A and C will be equal if the impedance to ground at A equals the impedance to ground at C. These impedances are equal. At C, looking toward A, we have a 150-ohm resistor in parallel with another 150-ohm resistor that we see and in parallel with the 72-ohm characteristic impedance of the coaxial lead-in that we see also. The total impedance to ground at C is, therefore, about 37 ohms. At A, looking toward C, and also looking into the lead-in, we have the 72-ohm characteristic impedance of the lead-in in parallel with the 150-ohm resistor at A and the 150-ohm resistor that we see at terminal C. Again, the total is 37 ohms. The a-c wave (signal) voltage at A is the voltage that comes from the antenna as its value develops on the 72-ohm lead-in. The voltage at C is equal in value to the voltage at A. Since both are applied to the 300-ohm balanced line, the signal voltage on the balanced line is double the voltage on the coaxial lead-in. In general, when transmission lines are matched together the voltage increases or decreases according to the square root of the impedance. Here, the impedance increases 4 times — from 75 ohms to 300 ohms. The voltage increases by the square root of four ($\sqrt{4}$) or 2 times.